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Procedia CIRP 14 (2014) 418 – 423

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6th CIRP International Conference on High Performance Cutting, HPC2014

Video based process observations of the pulse electrochemical machining process at high current densities and small gaps

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Abstract

Pulse Electrochemical Machining (PECM), a nontraditional process, using pulse-lengths in the low millisecond range as well as feed overlaid mechanical vibration, allows more precise tolerances and geometric precision through narrowing the working gap compared to conventional sinking ECM. With small working gaps in ranges down to 10µm, the anodic shape evolution during machining is getting difficult to monitor. Therefore understanding the shaping phenomena during the PECM process is key factor in achieving precision during the manufacturing of dies and molds, as well as precision parts in e.g. automotive or aircraft industry. In this contribution an experimental approach towards visual in-process observations of the PECM shaping process during the use of mechanical vibrations up to 50Hz and high pulsed current densities will be presented. Recording the process with a precisely clocked high speed camera system allowing precise µs shutter times, visual observations are conducted and being used as input for detailed downstream data analysis. The experimental study incorporates one of the most widely used flushing conditions in PECM as well as an outlook into the comparison between recorded in-process data and a static FEM simulation based on the monitored shape are given. In all experiments stainless steel of type AISI 304 (X5CrNi18–10) is used as anode and cathode material and for all PECM experiments a commercially available PEMCenter8000 with sodium nitrate as electrolyte was used. The concept presented will help to better link experiment and modelling of the PECM process, by simultaneously providing process relevant electrochemical data as well as the directly corresponding geometric shaping information during experiments.

Selection and peer-review under responsibility of the International Scientific Committee of the 6th CIRP International Conference on High Performance Cutting

Keywords: Identification, Precision, Electro chemical machining (ECM)

1. Introduction

Precision in Pulse Electrochemical Machining (PECM) - as a process development of the Electrochemical Machining (ECM) [1] - is dependent on detailed information about the material dissolution behavior under a variety of electrochemical conditions. Especially for modelling the process, detailed datasets are necessary [2, 3]. Conventionally, this knowledge is acquired through vast sets of experiments under different voltage, electrolyte, current density, feed etc. conditions [4]. This effort to understand the electrochemical behavior of a single material is very time consuming and requires multiple experiments, mainly under laboratory rather than actual production conditions. A good example of the amount of experiments necessary to investigate a single material can be found in the work of Altena [4]. Yet, herein no actual geometric shaping experiments were in the focus of the investigations. The main aim of this contribution is to present a new approach to combine aspects of determining the material dissolution behavior and at the same time also allowing geometric shaping experiments under industrial boundary conditions. Starting with a reference set of conventionally acquired material dissolution data the experimental setup, boundary conditions and downstream data analysis possibilities are presented. Unlike usual geometric shaping experiments, which most of the time only allow

Selection and peer-review under responsibility of the International Scientific Committee of the 6th CIRP International Conference on High Performance Cutting
doi:10.1016/j.procir.2014.03.105

geometric measurements before and after the experiment, this contribution will show the possibility to acquire geometric data during the experiments.

2. Experimental setup and equipment

2.1. The PECM process

The PECM process, schematically shown in Fig. 1, is a variation of the ECM process. During this process, the feed towards the workpiece (anode) is overlaid with a mechanical oscillation of the tool (cathode). The amplitude of the oscillation in this contribution is *200 µm*, which results in two different process phases. During the minimum gap size, a pulsed current with a pulse duration ranging from *0.1-5 ms* can be applied. The small gap size, achievable through the oscillation of the cathode, and the short current pulses of up to *8,000 A* lead to an effective material removal process resulting in good surface quality and precise copying accuracy [1]. The upward movement during the oscillation results in the phase of maximum gap size, which enables enhanced flushing possibilities and consequently a better removal of the processed material as compared to the conditions at minimum gap size.

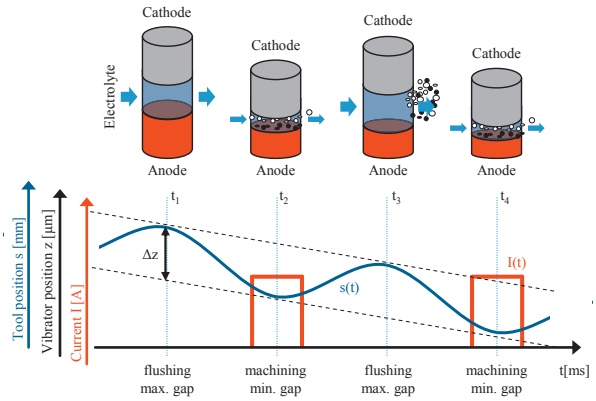

Fig. 1. PECM process schematic

Table 1. Experimental PECM parameters

Parameter	Total feed [mm]	Feed rate v_{feed} [mm/min]	Pressure p [kPa]	Voltage U [V]	$f_{mechanical}$ [Hz]	$f_{electric}$ [Hz]	P_{shift} [%]	t_{on} [ms]	Initial gap [µm]
Value	4	0.027	100	10	50	50	75	2.5	110

The phase shift P_{shift} *[%]* - as mentioned in Table 1 - relates to the shift of the pulse on-time t_{on} in relation to the bottom dead center of the mechanical vibrator. The starting time t_{shift} *[ms]* of the rising flank of the pulse on-time t_{on} *[ms]* can be calculated in relation to the point in time when the vibrator reaches the bottom dead center according to formula (1).

$$t_{shift}[ms] = -P_{shift}[\%] \cdot t_{on}[ms] \quad (1)$$

2.2. Material investigated

In this contribution, a stainless steel (1.4301, austenitic) is used as workpiece material. The chemical composition is listed in Table 2 in terms of minimum and maximum alloying element allowance by norm and as ICP-OES analysis result.

Fig. 2 represents the experimental results of the specific mass removal (SMR) in milligram per Coulomb of the workpiece material in a water based $NaNO_3$ electrolyte under different current densities acquired in experiments using a custom build PECM setup. Fig. 3 shows the frontal gap as well as feed rate dependencies of the used material for different current densities.

The fit in Fig. 2 is done according to [4]. The experimental boundary conditions under which the data in Fig. 2 and Fig. 3 were determined are as follows:

- $NaNO_3$ concentration *75 g/l* (technical pure)
- Electrolyte conductivity *σ = 70.5 mS/cm (± 1mS/cm)*
- Temperature *T = 21°C (± 1°C)*
- pH number *7.1 pH (± 0.2pH)*
- average flow rate *4.7 l/min (± 0.2 l/min)*
- pulse on time t_{on} *= 2.5ms* (at f=50Hz)
- Voltage *10 V*

Table 2. Material investigated [in Weight-%]

Name	1.4301		X5CrNi18-10		AISI 304					
Element	C	Si	Mn	P	S	Cr	Ni	N	Cu	Fe
min.	0.00	0.00	0.00	0.000	0.000	17.0	8.00	0.00	0.0	75
max.	0.07	1.00	2.00	0.045	0.015	19.5	10.5	0.11	1.0	66.885
ICP-OES	-	0.83	1.92	0.13	-	17.72	10.16	-	0.33	68.89

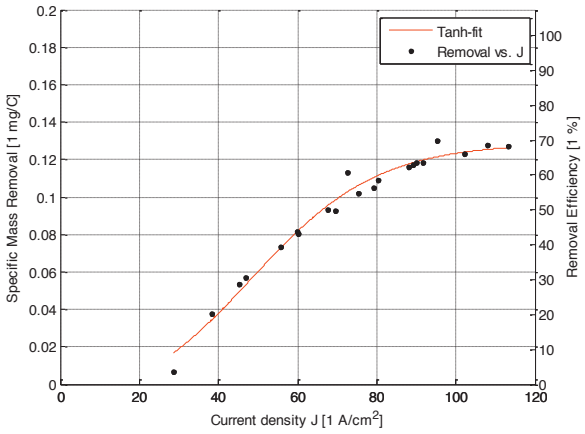

Fig. 2. Specific Mass Removal and Removal Efficiency for material 1.4301 at different current densities (R^2=0.9809)